Improving Formulation of Marine Stable Boundary Layers Using CBLAST Weak Wind Data

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LONG-TERM GOAL

The long-term goals are to better understand air-sea exchange of momentum, heat and moisture and its impact on the marine boundary layer and to better understand the influence of SST variations on the area-averaged (grid-averaged) flux-gradient relationship. Substantial modification of the formulation of the surface moisture flux for all conditions and the boundary layer for very stable conditions are also long term goals.

OBJECTIVES

The objectives are to quantify the influences of surface heterogeneity and strong stability on the transfer coefficients for the bulk formula and to formulate the difference between the transfer coefficients for momentum, heat and moisture.

APPROACH

Analyze the LongEZ eddy-correlation data in the CBLAST Weak Wind Pilot Experiment 2001 and compare with eddy-correlation data from the CBLAST WHOI ASIT tower during the intensive period and prior to the intensive period. LongEZ data from SHOWEX will be incorporated for comparison. We will also analyze eddy-correlation data collected by the CIRPAS Pelican during the CBLAST Weak Wind Experiment. The analyzed fluxes will be used for evaluation of regional modeling and LES simulations.

WORK COMPLETED

The work during the past year concentrated on the formulation of surface moisture and heat fluxes and work with Eric Skyllingstad comparing LES results with our observational analyses. We have completed a more extensive analysis of the difference between the roughness lengths for heat and moisture and difficulties with current models. We have been unable to obtain the corrected profile data from the ASIT tower, but expect such data by the beginning of October.

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RESULTS

Our results indicate that current bulk formulas commit substantial errors for prediction of moisture fluxes over the sea. We have framed these results in terms of the difference between the roughness lengths for moisture and heat. Current formulations generally equate these two roughness lengths although an earlier version of the TOGA COARE algorithm specified the roughness length for moisture to be slightly higher than that for heat. We find that such assumptions are suitable for the tropics where the moisture flux contributes substantially to the buoyancy flux, and subsequent buoyancy generation or destruction of turbulence. However, for mid-latitudes where the moisture flux contributes insignificantly to the buoyancy flux, we find that the roughness length for moisture is one or two orders of magnitude smaller than that for heat. Numerous studies over land have also found less efficient transport of moisture compared to heat.

While the difference between the tropical and mid-latitude seas is substantial and consistent with the relative contributions of the heat and moisture flux to the buoyancy flux, the variation of the ratio of the moisture and heat roughness lengths within a given dataset is more complex. Here, we show results for the combined SHOWEX and CBLAST Weak Wind datasets. The ratio of the roughness lengths is proportional to the ratio of transport efficiencies, as reflected by the ratio of the correlation coefficients between the vertical velocity fluctuations and temperature or moisture fluctuations (Figure 1).

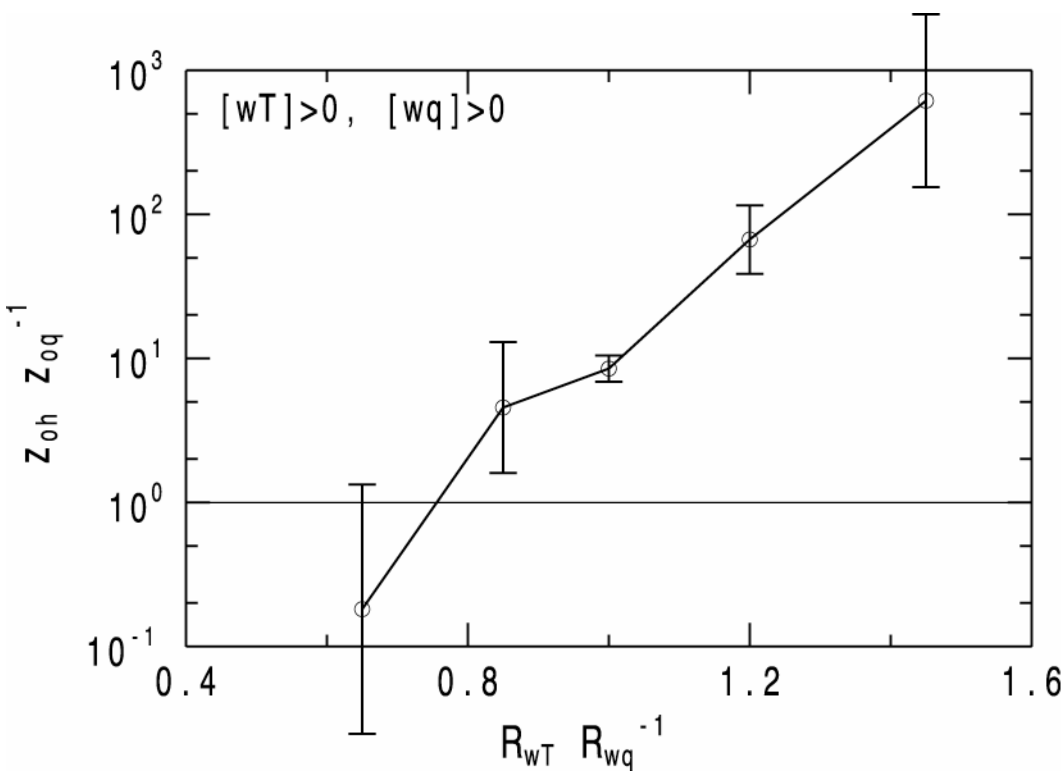

Figure 1: Averaged values of the ratio of the heat and moisture roughness lengths as a function of the ratio of the correlation coefficients for the CBLAST Weak Wind and SHOWEX datasets combined. The relative value of the scalar roughness length is proportional to the relative transport efficiency, as represented by the correlation coefficient with vertical velocity fluctuations.

If the contribution to the buoyancy flux was known to be the dominating influence on the differences in heat and moisture flux efficiencies, then differentiation between the stability functions for heat and moisture might be preferable to variable roughness lengths. However, in addition to the contribution of the heat and moisture fluxes to the buoyancy generation/destruction of turbulence, the ratio of roughness lengths is influenced by:

1. Surface moisture fluxes are more suppressed by surfactants than heat fluxes.

2. Possible preferential loss of moisture flux due to greater separation between the gust probe (BAT probe) and measurement of moisture fluctuations, as compared to the separation between the gust probe and temperature-fluctuation measurements. Assessment of such flux loss indicates small errors, but uncertainties remain.

3. The vertical structure of the heat and moisture fluxes within the boundary layer are generally different, depending on the role of entrainment of dry air at the top of the boundary layer. Typically, the height dependence of the fluxes would lead to greater underestimation of the surface heat flux by the aircraft (due to height dependence of the heat flux) compared to analogous errors for the surface moisture flux, and therefore not an explanation for the smaller moisture roughness lengths. We have attempted to correct our fluxes for flux divergence between the aircraft level (10-15 m) and the surface, although the accuracy of such corrections is less certain for stable conditions.

4. In addition to the analysis problem (3), the role of dry air entrainment introduces different physics for the transport of the heat and moisture. The moisture flux might be preferentially transported by the larger eddies compared to the heat flux.

5. Differences between the transport efficiencies of heat and moisture over land have been related to microscale variation of the sources of surface heat and moisture fluxes. Such differences could also occur over the sea, particularly for strong winds where the moisture flux might preferentially originate from the breaking part of the wave.

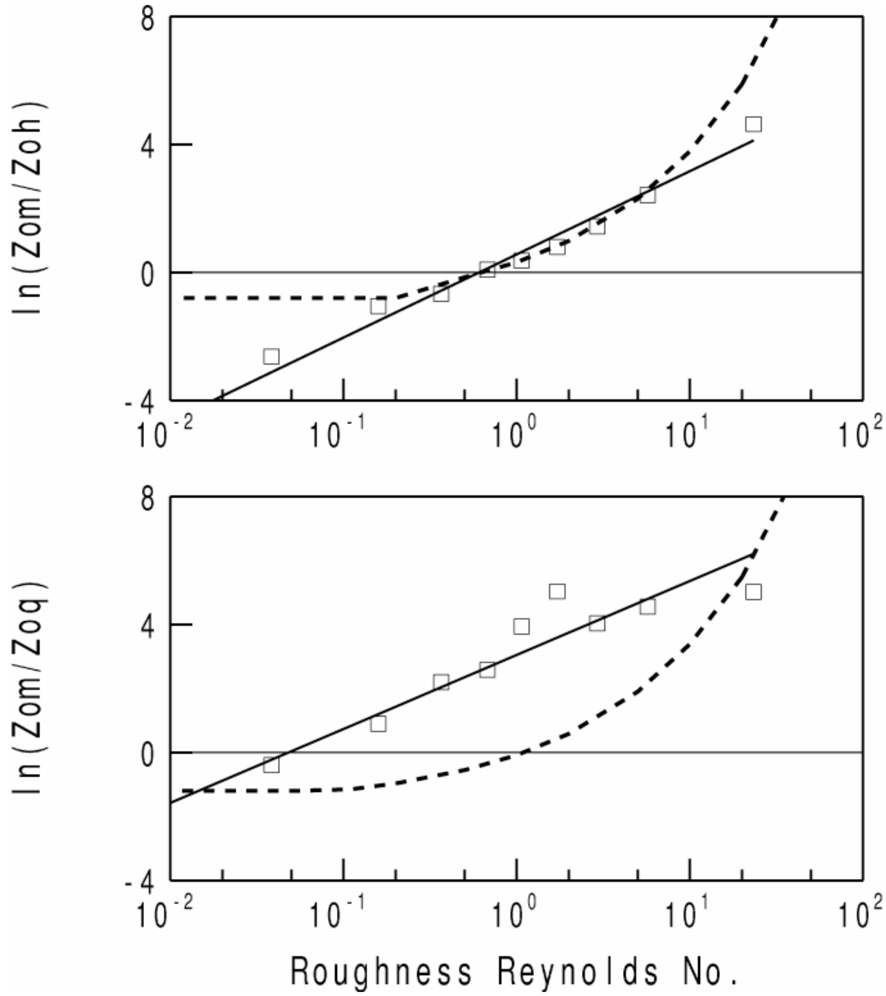

Figure 2: The logarithm of the roughness length ratios as a function of roughness Reynolds number for SHOWEX and CBLAST Weak Wind combined datasets. The straight lines are models of the scalar roughness lengths derived from the existing data, the dashed curves are from Zilitinkevich et al. (2001) and the squares are bin-averaged observations.

Our preliminary model of the roughness lengths for heat and moisture are indicated by the straight lines in Figure 2.

As a secondary task, we created analysis products from the LongEZ flights over SST variations and compared them with the LES results of Eric Skyllingstad. A basic scenario was examined in terms of two configurations of SST variations with alternating warm/cold or cold/warm water. The LES results were better able to describe the internal boundary layer development for the cases of flow from cold to warm water than warm to cold. The effect of the thermally-induced pressure gradient was found to be small compared to the change of flux divergence of momentum.

RELATED PROJECTS

We will soon receive corrected profile information from the ASIT tower, which will allow us to re-examine the flux parameterizations jointly with Jim Edson. We have recently initiated work with Shouping Wang. We are providing him with information on the roughness lengths for moisture and heat for specification in his model. We have also initiated interaction with QingWang on the analysis of data from their CBLAST eddy-correlation tower. We will continue our joint work with Eric Skyllingstad on comparison between the CBLAST Weak Wind aircraft data and his LES model results.

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